Chapter 9. Grand Canyon National Park

Introduction

The Grand Canyon was established as a forest reserve in 1893, and later became the Grand Canyon Game Preserve in 1906, the Grand Canyon National Monument in 1908, and finally the Grand Canyon National Park in 1919. A separate Grand Canyon National Monument was established west (downriver) of the Park in 1932, and Marble Canyon National Monument was created in 1969 to the northeast (upriver). The National Park reached its present size of over 492,800 ha when Grand Canyon and Marble Canyon National Monuments were added along with additional area around Toroweap and upper Lake Mead (Figure 9-1). In 1979, Grand Canyon National Park was designated a World Heritage Site because of the tremendous natural and geologic value contained in the Park.

Grand Canyon National Park is in northern Arizona, with park headquarters about 100 km north of Flagstaff. Over 400 km of the Colorado River are included in the Park. Neighboring lands include the Kaibab National Forest, Glen Canyon and Lake Mead National Recreation Areas, the Arizona Strip District of the BLM, and reservations belonging to the Navajo, Hualapai, and Havasupai tribes.

The exposed geology of the canyon spans 2 billion years and a maximum drop in elevation of about 1860 m. The region of the Grand Canyon National Park includes seven plateaus, including the Kanab, Kaibab, and Coconino and the low lying Marble Platform that are separated by many faults and monoclines. Elevations for the Grand Canyon National Park range from 353 m at Lake Mead to almost 2800 m on the North Rim. Because of the dramatic topography and huge elevational changes, climate is extremely variable in temperature and moisture. The Park contains an abundance of archeological sites.

Geology and Soils

The oldest formation in the Grand Canyon National Park is the Vishnu Schist (Chronic 1988), which comprises the Inner Gorge. The Vishnu, Brahma and Rama Schists are the highly metamorphosed sediments eroded from mountains more than 2 billion years ago off the “coast” of North America. The schist has major intrusions of pink Zoroaster Granite (from about 1.75 million years ago). The rocks were later “welded” onto the North American tectonic plate (Bradley et al.

1996). In the late Precambrian (1250-825 million years ago) over 3 km of sediments and lava were deposited (forming the Grand Canyon Supergroup, Elston 1989). Later uplift, tilting, and erosion removed most of this material. Only a few tilted, wedge-shaped layers remain in the eastern end of the Park, beneath the “Great Unconformity.” From 500 to 245 million years ago, coastal environments dominated the Grand Canyon area as gradual sinking allowed deposition of sedimentary layers. Early Paleozoic marine deposits include the beach sands of Tapeats Sandstone and off-shore deposits of limestones (Muav, Temple Butte, Redwall).

Mountain building to the east of the Grand Canyon in the later Paleozoic provided sedimentary materials for the Supai Group, Herman Shale, and Coconino Sandstone. Occasional marine advances provided material for Pakoon, Toroweap, and Kaibab Limestones.

In the Mesozoic era, about 1500 m of additional strata were deposited in the Grand Canyon area, but subsequent uplift led to massive erosion of these strata that can still be seen in other regions of the Colorado Plateau.

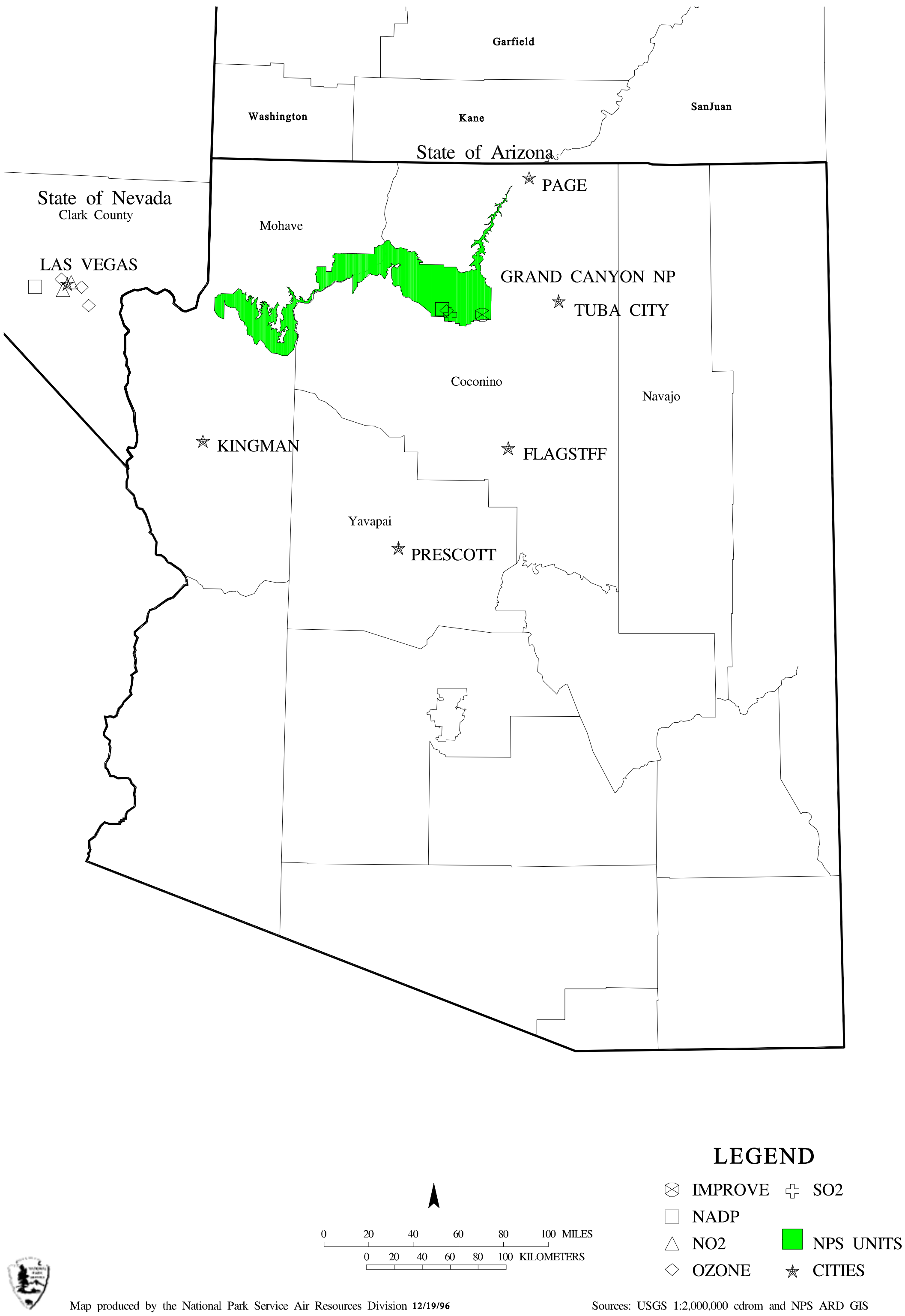
The carving of the Grand Canyon probably occurred over a period of 6 million years, with the Canyon reaching its current depth about 1 million years ago based on dating of exposed volcanic flows in the bottom of the Canyon.

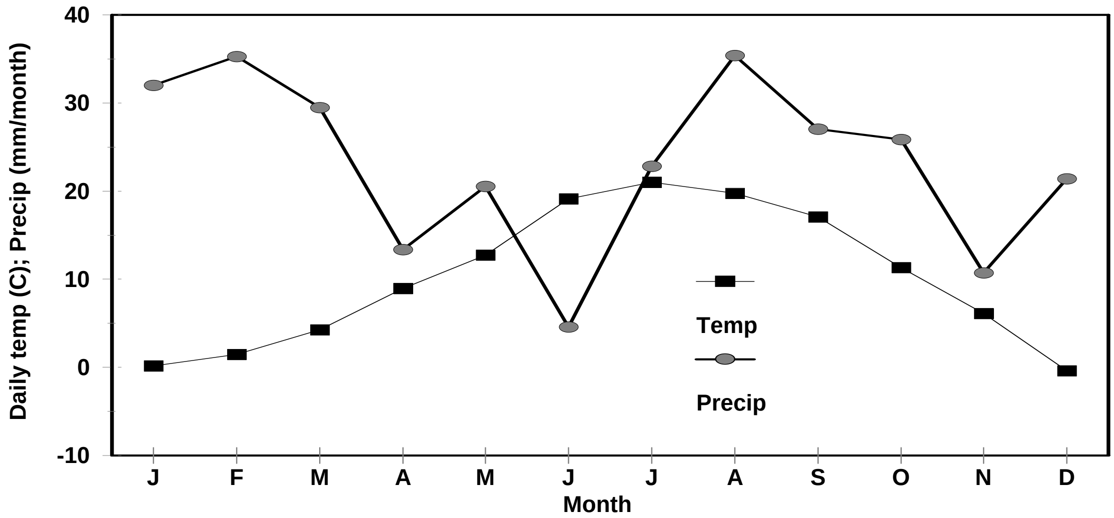
The soils of the Grand Canyon National Park strongly reflect the parent materials and dry climate, and none should be sensitive to acidification from acid deposition.

Climate

The tremendous elevational gradient in the Grand Canyon results in huge variation in temperatures and moisture with corresponding changes in vegetation. The mean monthly temperature for January and July at the South Rim are -2 ^{o}C and 19 ^{o}C, with an average total precipitation of 500 mm/yr (Figure 9-2). Temperatures at the bottom of the Canyon average about 3-5 ^{o}C warmer, and precipitation declines by about half down to the river. The winds at the South Rim come predominantly from the southwest, except for late autumn when substantial winds also come from the northeast (Figure 9-3).

Figure 9-1. Location of Grand Canyon National Park.




40
30
20
10
0
-10
Daily temp (C); Precip (mm/month)
J
F
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A
M
J
J
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Month
Temp
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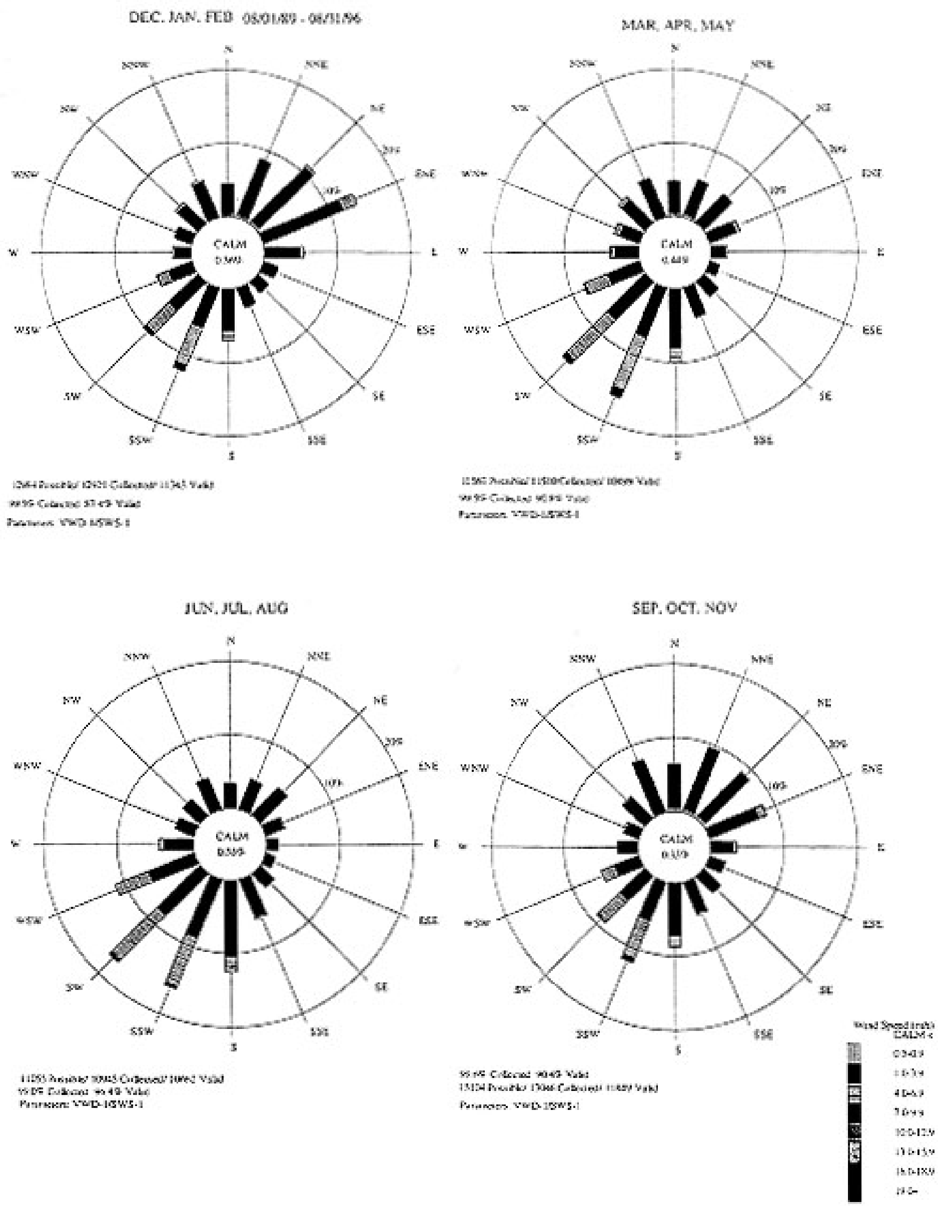
Figure 9-3. Seasonal wind roses for Grand Canyon National Park for 1989-1996.

Grand Canyon Air Quality 9-5

Figure 9-3. Seasonal wind roses for Grand Canyon National Park for 1989-1996.



Vegetation

Grand Canyon National Park has a wide variety of vegetation communities, from very arid communities characteristic of deserts of southern Arizona and California to conifer forests characteristic of the Rocky Mountains (Table 9-1). The communities along the river and lower reaches of tributary canyons include Fremont cottonwood (*Populus fremontii*), mesquite (*Prosopis juliflora*), acacia (*Acacia greggii*), and a variety of native willow species including coyote willow (*Salix exigua*) and Goodding willow (*Salix gooddingii*). Most low-elevation riparian zones have major infestations of exotic tamarisk (*Tamarix ramosissima*). At lower elevations (typically below the Redwall) away from water sources, Mojave and Sonoran Desert scrub communities dominate, with blackbrush (*Coleogyne ramosissima*), saltbush (*Atriplex canescens*) creosote bush (*Larrea tridentata*), Mormon tea (*Ephedra* spp.), snakeweed (*Gutierrezia sarothrae*) and various cactus species. The mid-elevation vegetation is typically dominated by the pinyon (*Pinus edulis*) / juniper (*Juniperus osteosperma*, *J. monosperma*) community from the top of the Redwall into the Coconino sandstone. Ponderosa pine (*Pinus ponderosa*) communities mixed with Gambel oak (*Quercus gambelii*) cover extensive areas of the South Rim and lower elevations of the North Rim. Communities of spruce (*Picea engelmannii*) and white fir (*Abies concolor*) on the North Rim include aspen (*Populus tremuloides*) and Douglas-fir (*Pseudotsuga menzeisii*). Riparian communities in the Grand Canyon National Park include mesic plant communities with Fremont cottonwood (*Populus fremontii*), single leaf ash (*Fraxinus anomala*), hoptree (*Ptelea trifoliata*), hophornbeam (*Ostrya knowltonii*), serviceberry (*Amelanchier utahensis*), redbud (*Cercis occidentalis*), Apache plume (*Fallugia paradoxa*), squawbush (*Rhus trilobata*) and many others. The Grand Canyon National Park has only one plant species listed as endangered: the Sentry milkvetch (*Astragalus cremnophylax* var. *cremnophylax*) (Threatened and Endangered Species Information Institute 1993). Species of special concern for the NPS include: bear paw poppy (*Arctomecon californica*), Roaring Springs prickle poppy (*Argemone arizonica*), bunchflower evening primrose (*Camissonia confertifolia*), cave dweller primrose (*Camissonia specuicola* ssp. *hesperia*), Grand Canyon rose (*Rosa stellata* ssp. *abyssa*), Grand Canyon catchfly (*Silene rectiramea*), and Tusayan flame flower (*Talinum validulum*). None of these plants are suspected of being threatened by air quality. A full listing of plant species in the Park is provided in NPFlora, and lichen species are listed in NPLichen.

Table 9-1. Vegetation communities which comprise > 0.1% of Grand Canyon National Park (provided by NPS staff, Grand Canyon National Park).

Community type	% of Park
Snakeweed-Mormon Tea-Utah Agave	10.8
Blackbrush-Mormon Tea-Banana Yucca	9.4
Juniper-Pinyon-Mormon Tea-Scrub Oak	6.8
Juniper-Big Sagebrush-Pinyon	5.7
Mormon Tea-Snakeweed-Wolfberry	5.4
Pinyon-Scrub Oak-Manzanita	5.1
Brittlebush-Creosotebush-Mormon Tea	5.0
Scrub Oak-Snakeweed-Beargrass-Blackbush	4.7
Blackbrush-Pinyon-Juniper	4.4
Desert Mallow-Mormon Tea-Creosotebush	3.5
Brittlebush-Mormon Tea-Catclaw Acacia	3.1
Juniper-Pinyon-Mormon Tea-Greasebush	2.9
Mormon Tea-Blackbrush-Creosotebush	2.8
Big Sagebrush-Snakeweed-Mormon Tea	2.6
Ponderosa-White Fir-Aspen	2.3
Pinyon-Serviceberry-Gambel Oak	2.2
Ponderosa-Pinyon-Gambel Oak-Juniper	1.8
Pinyon-Juniper-Big Sage-Cliffrose	1.7
Pinyon-Juniper-Scrub Oak-Little Leaf Mtn Mahogany	1.5
Big Sagebrush-Juniper-Pinyon	1.5
Big Sagebrush-Snakeweed-Blue Gramma	1.5
Sandpaper bush-Pinyon-Snakeweed	1.3
Engelmann Spruce-White Fir-Ponderosa	1.3
Ponderosa-Aspen-White Fir-Douglas Fir	1.3
Ponderosa Pine	1.1
Juniper-Pinyon-Big Sagebrush	0.9
Ponderosa-NMex Locust-Gambel Oak	0.7
Creosotebush-White Bursage-Mormon Tea	0.7
Mormon Tea-Big Galleta-Catclaw Acacia	0.7
Saltbush-Banana Yucca-Snakeweed	0.6
Pinyon-Juniper-bluegrass	0.6
Desert Mallow-Indigo bush-Ocotillo	0.6
Creosotebush-Beavertail Cactus-Ocotillo	0.5
Shadscale-Mormon Tea-Beavertail Cactus	0.5
Blackbrush-Banana Yucca-Cliffrose	0.5
Engelmann Spruce-Subalpine Fir	0.5
Mixed Grass-forb Association	0.4
Ponderosa-Gambel Oak-White Fir-NMex Locust	0.4
White Bursage-Mormon Tea-Barrel Cactus	0.3
Douglas Fir-White Fir-NMex Locust	0.3
Black Sagebrush-Saltbush-Mormon Tea	0.2
Big Sagebrush-Saltbush-Mormon Tea	0.2
Hilaria-Cheatgrass-Snakeweed	0.2
Catclaw Acacia-Baccharis-Apache Plume	0.2
Ponderosa-Aspen-Engelmann Spruce	0.2
Fourwing Saltbush-Winterfat-Mormon Tea	0.2
Rabbitbrush-Snakeweed-Fourwing Saltbush	0.2
Ponderosa-Gambel Oak-Big Sagebrush	0.1
Blackbrush-Joshua Tree-Banana Yucca	0.1
Cottonwood-Brickellia-Acacia-Apache Plume	0.1

Aspen-Ponderosa-Engelmann Spruce	0.1
Fourwing Saltbush-Big Sagebrush-Snakeweed	0.1
Ponderosa-Pinyon-Cliffrose-Black Sagebrush	0.1

Air Quality

Air quality monitoring for the Grand Canyon consists of ozone monitoring (1983, 1989-present, and 1995/1996 as part of the EPA CASTNet program), NADP monitoring from 1981 to the present, NDDN estimates of dry deposition for 1990-1991, SO_2 measurements from 1988-present (omitting 1990), and IMPROVE monitoring for visibility from 1988 to the present. Three photographs/day are taken for visibility at Desert View. A nephelometer is planned for installation at Grandview Point. Air quality issues at the Grand Canyon National Park and other Class I areas of the Colorado Plateau were the focus of the GCVTC (1996) which was mandated in the 1990 Clean Air Act Amendments. A USDA ultraviolet radiation monitoring station was set up in 1996, and the State of Arizona has monitored airborne particulate radiation at two sampling sites on the South rim since 1994 (Arizona Radiation Regulatory Agency 1994).

Emissions

Table 9-2 provides summaries for emissions of carbon monoxide (CO), ammonia (NH_3), nitrogen oxides (NO_x), volatile organic compounds (VOC), particulate matter (PM), and sulfur oxides (SO_x) for 8 counties surrounding the Grand Canyon National Park. These local emissions are relatively low, with the exception of Coconino County's Navajo Generating Station of the Salt River Project. A micro-inventory of emissions was developed for 1993 for the Grand Canyon (Radian 1994b; C. Bowman, personal communication). The micro-inventory found that mobile sources (vehicles on roads, boats, and aircraft) were the predominant sources of visibility-reducing pollutants (Table 9-3), with prescribed fires contributing less than half of the local emissions. The Park did not add appreciably to the total emissions of Coconino County, although local emissions are higher than those typically used to represent "rural" areas. The GCVTC (1996) concluded that emissions from source areas of pollution for Grand Canyon National Park should decline by about 30% from the 1990 levels by sometime between 2000 and 2010, as a result of improved emission control for point sources and declining emissions from the copper smelting industry.

Table 9-2. Emissions (tons/day) for counties surrounding Grand Canyon National Park (Radian 1994a).

County	CO	NH_3	NO_x	VOC	PM	SO_X
Garfield, UT	13.69	0.60	1.5	63	253	0.2
Kane, UT	14.88	0.26	1.6	44	114	0.2
San Juan, UT	40.75	0.66	3.9	103	405	0.5
Washington, UT	63.71	0.55	6.5	34	189	0.9
Coconino, AZ	145.54	3.17	132.8	209	659	213.2
Mohave, AZ	99.74	1.16	22.0	224	784	1.5
Navajo, AZ	167.34	2.74	78.8	83	559	67.7
Yavapai, AZ	144.08	2.71	27.1	114	653	2.6
Clark, NV	580.40	1.64	187.2	117	606	128.0

Table 9-3. Micro-inventory of emissions in Grand Canyon National Park in 1993 (Radian 1994b, C. Bowman, personal communication). Wildfires and prescribed fires not included.

Source category	SO_2	NO_x	Particulate Matter	Volatile Organic Compounds
Commercial/Institutional fuel combustion	14.0	12.0	0.7	0.7
Residential fuel combustion (LPG)		0.1		
Residential wood combustion	0.1	0.7	7.8	6.5
Highway vehicles - gasoline	6.2	150.0	2.3	160.0
Highway vehicles - diesel	28.0	170.0	16.0	39.0
Aircraft	6.5	84.0	17.0	69.0
Recreational boating - gasoline	2.9	8.6	47.0	870.0
Trains - diesel	1.4	2.5	0.1	0.1
Road dust from paved roads			1950.0	
Commercial charbroiling			0.6	

Solvents from surface coatings				15.0
Road paving - cutback asphalt				16.0
Consumer solvents				15.0
Storage tanks - gasoline & diesel				19.0
Waste disposal - landfills				<0.1
Charcoal combustion - campfires	0.02	0.2	2.0	1.5

Air Pollutant Concentrations

The concentrations of ozone between 1983 and 1994 averaged about between 25 and 50 ppb, with peak 1-hr concentrations of up to 80 ppb (Table 9-4). These concentrations fall within a range that may produce visible effects or growth effects on very sensitive species (see Chapter 2), but no reports of injury or growth effects have been noted. The concentrations of SO_2 were far below any threshold of suggested sensitivity for any plants.

Beta radiation from airborne particles in 1994 was low at the Grand Canyon, averaging between 10 and 20 femtocuries/m^3 of air (Arizona Radiation Regulatory Agency). These values should provide a useful “baseline” condition if uranium mining resumes in the region (thousands of mining claims surround the Park; C. Bowman, personal communication).

Van Ee (1979) measured concentrations of CO at the south entrance to the Grand Canyon National Park for 2.5 days in August of 1978. This unpublished report found concentrations varied between 16 ppm (at night) and 44 ppm (early to late morning), with an 8-hour mid-day average of about 30 ppm. The primary standards for CO (Chapter 1) are about 9 ppm for 8 hr and 34 ppm for 1 hr, so workers at the entrance station in 1978 may have been exposed to excessive levels of CO.

Table 9-4. Concentrations of ozone and SO_2 for Grand Canyon National Park between May and September. For ozone, upper value is mean daily concentration (ppb); middle number is the maximum 3-month Sum60 exposure (ppb-hr in excess of 60 ppb for 12 hr/day); and bottom number is the maximum 1-hr concentration observed each year. SO_2 24-hr averages by IMPROVE filter samplers (ppb) (1 $\mu g/m^3$ approximately equals 0.38 ppb). Ozone data from the NPS Air Resources Division's Quick Look Annual Summary Statistics Reports (provided by D. Joseph, NPS-ARD).

Year	Ozone	SO_2
1983		
Mean	26	
Sum60	132	
Max	66	
1988	--	
Mean		0.2
Sum60		
Max		1.1
1989		
Mean	43	0.2
Sum60	--	
Max	68	1.0
1990		
Mean	43	
Sum60	--	--
Max	74	
1991		
Mean	46	0.2
Sum60	21922	
Max	79	1.1
1992		
Mean	44	0.1
Sum60	10416	
Max	78	0.6
1993		
Mean	46	0.2
Sum60	7228	
Max	73	2.7
1994		
Mean	49	0.1
Sum60	12542	

Max	79	0.9

Visibility

Equipment has been placed to monitor visibility conditions on the rim and inside the Grand Canyon. One aerosol sampler is on the South Rim at Hopi Point, and a second aerosol sampler is located in the canyon at Indian Gardens. One transmissometer is sighted along the South Rim near Grandview Point, with measurements beginning in December of 1986. Another transmissometer has a sight path from Yavapai Point on the South Rim to the canyon floor, with data collection beginning in December of 1989. The aerosol sampler at Hopi Point began operation in March 1988, the aerosol sampler at Indian Gardens began operation in October 1989. A camera began recording images in October 1979.

The data from this IMPROVE site have been summarized to characterize the full range of visibility conditions for the period December 1986 through February 1994. The seasons used are: spring = March, April, and May; summer = June, July, and August; autumn = September, October, and November; and winter = December, January, and February.

Optical Data - Transmissometer

The transmissometer system consists of two individually-housed primary components: a transmitter (light source) and a receiver (detector). The atmospheric extinction coefficient (b_{ext}) at any time can be calculated based on the intensity of light emitted from the source and measured by the receiver (along with the path length between the two). Transmissometers provide continuous, hourly b_{ext} measurements. Weather factors such as clouds and rain can affect transmissometer measurements, but these can be "filtered out" by removing data points with high relative humidities (RH>90%).

The data are presented by season and annual median values, with and without meteorological factors in Table 9-5 Transmissometer Data Summary. The data are presented in units of extinction coefficient in Mm^{-1} and standard visual range in km. Extinction coefficients represent the ability of the atmosphere to scatter and absorb light. Median values with large differences between the extinction values "including weather" and "excluding weather" indicate periods dominated by precipitation. Higher extinction coefficients signify lower visibility. Similarly, season and annual medians with nearly equal "including weather" and "excluding weather" extinctions indicate visibility reduction caused principally by particles.

Table 9-5. Transmissometer data summary for the South Rim of the Grand Canyon for 1987-1994. SVR = visual range; b_{ext} = light extinction coefficient.

Season Year	Excluding Weather		Including Weather	
	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})
Winter 1987	189	20	173	22
Spring 1987	153	25	147	26
Summer 1987	199	19	189	20
Autumn 1987	181	21	173	22
Annual 1987	199	19	287	13
Winter 1988	287	13	235	16
Spring 1988	189	20	173	22
Summer 1988	137	28	132	29
Autumn 1988	147	26	141	27
Annual 1988	173	22	159	24
Winter 1989	181	21	165	23
Spring 1989	165	23	159	24
Summer 1989	147	26	147	26
Autumn 1989	210	18	210	18
Annual 1989	173	22	165	23
Winter 1990	235	16	222	17
Spring 1990	147	26	141	27
Summer 1990	159	24	153	25
Autumn 1990	199	19	189	20
Annual 1990	181	21	165	23
Winter 1991	189	20	181	21
Spring 1991	153	25	147	26
Summer 1991	159	24	159	24
Autumn 1991	165	23	153	25
Annual 1991	165	23	153	25
Winter 1992	181	21	153	25
Spring 1992	153	25	147	26
Summer 1992	165	23	159	24
Autumn 1992	181	21	173	22
Annual 1992	173	22	165	23
Winter 1993	210	18	147	26
Spring 1993	165	23	159	24
Summer 1993	107	36	99	39
Autumn 1993	153	25	141	27
Annual 1993	159	24	153	25
Winter 1994	235	16	222	17
Spring 1994	153	25	147	26

Summer 1994	173	22	165	23
Autumn 1994	189	20	189	20
Annual 1994	181	21	173	22

Visibility tends to be lowest in the spring and summer, when the visibility range is notably lower than in the winter (Table 9-6).

Table 9-6. Standard visual range for the South Rim of Grand Canyon National Park. Seasonal averages for median standard visual range in km from 1986 through 1994.

Season	Excluding Weather	Including Weather
Winter	213	187
Spring	160	152
Summer	156	150
Autumn	178	171

Aerosol Data

Aerosol sampler data are used to reconstruct the atmospheric extinction coefficient from experimentally determined extinction efficiencies of certain species (Table 9-7). To compare this table with the data from Tables 9-6 and 9-5, the "excluding weather" values should be used. In Table 9-7 the data are presented as seasonal and annual 50th and 90th percentile standard visual range for the Grand Canyon. The 50th percentile means that visual range is this high or lower 50% of the time. This is an average 50th percentile for each season. The 90th percentile means that the visual range is this high or lower 90% of the time. This is an average 90th percentile for each season.

The reconstructed extinction data are used as background conditions to run plume and regional haze models. These data are also used in the analysis of visibility trends and conditions. The measured extinction data are used to verify the calculated reconstructed extinction and can also be used to run plume and regional haze models and to analyze visibility trends and conditions.

Because of the larger spatial and temporal range of the aerosol data, the use of the reconstructed extinction data are preferred.

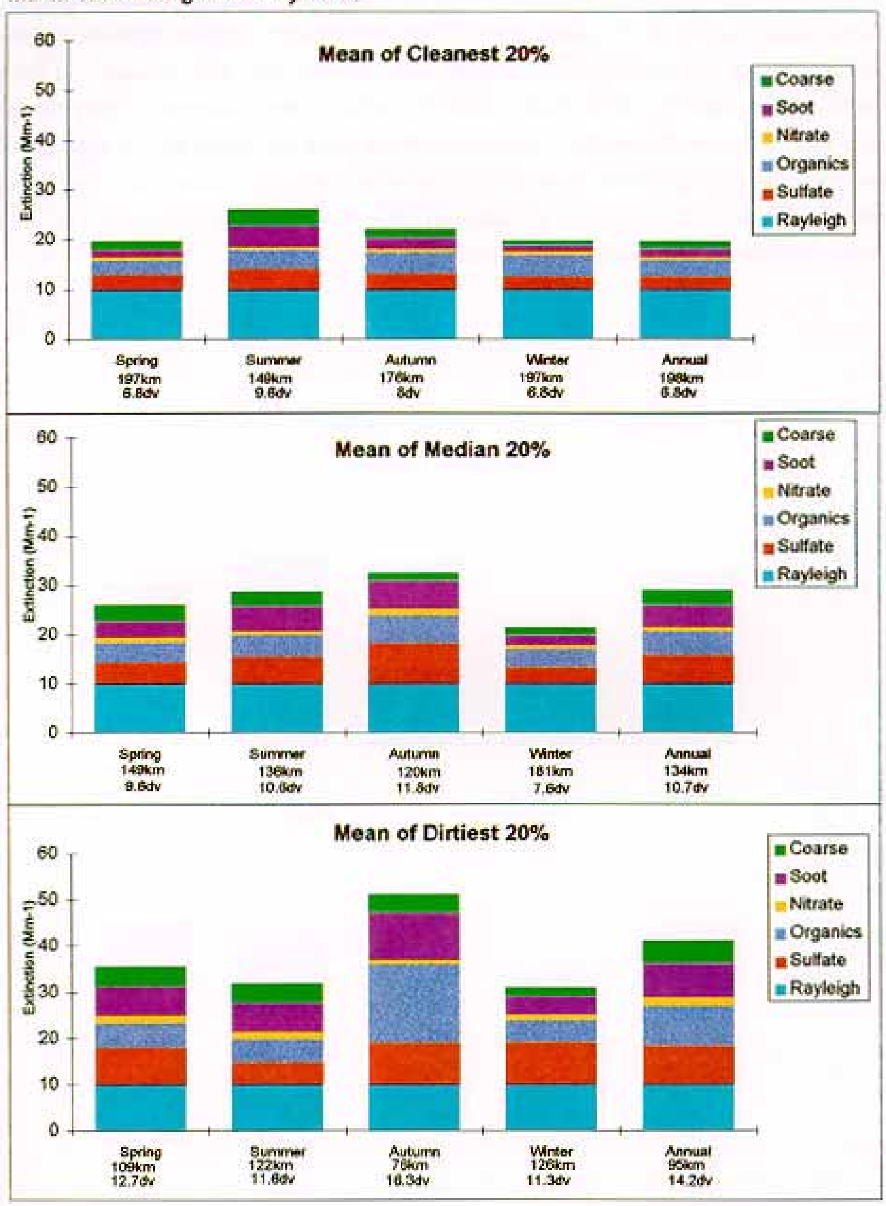
Table 9-7. Reconstructed visual range and light extinction coefficients for Grand Canyon National Park, based on IMPROVE aerosol sampler, seasonal and annual average 50th and 90th percentiles, March 1988 - February 1994.

Season/Annual	50th Percentile Visual Range (km)	50th Percentile b_{ext} (Mm^{-1})	90th Percentile Visual Range (km)	90th Percentile b_{ext} (Mm^{-1})
Winter	165	23.6	225	17.3
Spring	138	28.4	185	22.1
Summer	120	32.6	155	25.2
Autumn	132	29.6	194	20.2
Annual	133	29.5	203	19.3

Reconstructed extinction budgets generated from aerosol sampler data apportion the extinction at the South Rim to specific aerosol species (Figure 9-2). Visibility impairment is attributed to atmospheric gases (Rayleigh scattering), sulfate, nitrate, organics, soot, and coarse particles. The extinction budgets are listed by season and by mean of cleanest 20% of days, mean of median 20% of days, and mean of dirtiest 20%of days. The "dirtiest" and "cleanest" signify highest fine mass concentrations and lowest fine mass concentrations respectively, with "median" representing the 20% of days with fine mass concentrations in the middle of the distribution. Each budget includes the corresponding extinction coefficient, SVR, and haziness in dv. The sky blue segment at the bottom of each stacked bar represents Rayleigh scattering which is assumed to be a constant 10 Mm^{-1} at all sites during all seasons. Rayleigh scattering is the natural scattering of light by atmospheric gases. Higher fractions of extinction due to Rayleigh scattering indicates cleaner conditions.

Figure 9-4. Reconstructed extinction budgets for the South Rim, March 1993 through February 1994.

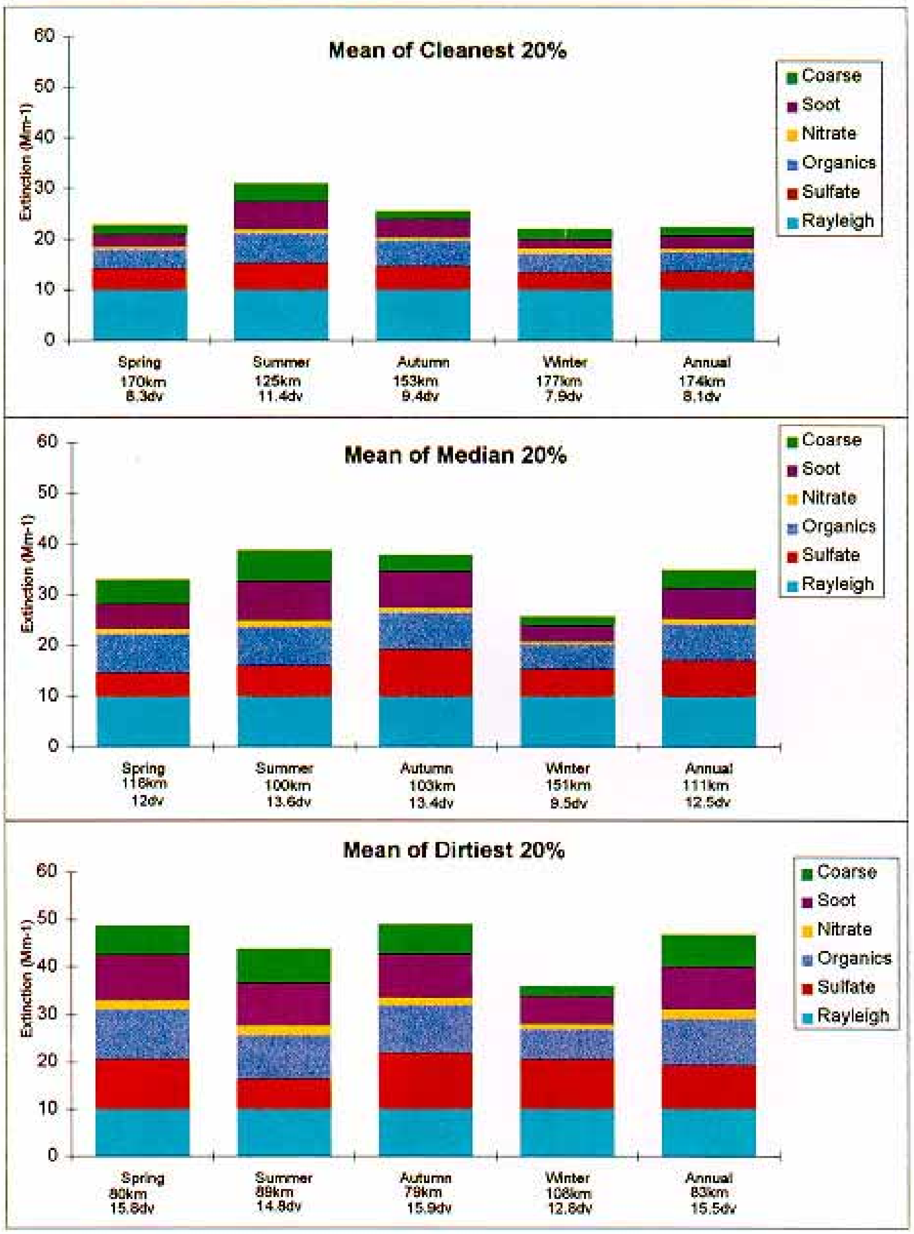
Figure 9-4. Reconstructed extinction budgets for the South Rim, March 1993 through February 1994.



Atmospheric light extinction at the South Rim of the Grand Canyon National Park, like many rural western areas is largely due to sulfate, organic, and soot aerosols. Sulfates, organics, and soot contribute roughly equally to extinction on dirty, median, and clean days annually. At Indian Gardens, sulfates, organics, and soot also contribute roughly equally to extinction on dirty, median, and clean days annually (Figure 9-5). Visibility conditions inside the canyon are 2-4 dv lower than those on the rim during all four seasons based on either aerosol or optical data. The highest median extinctions occur in summer and autumn both in the canyon and on the rim. The lowest median extinctions occur in winter for both locations.

Figure 9-5. Reconstructed extinction budgets for Indian Gardens, March 1993 through February 1994.

Figure 9-5. Reconstructed extinction budgets for Indian Gardens, March 1993 through February 1994.



The mean of the median 20% represents the average visibility conditions at the South Rim. On the average days, normal light scattering by the natural gases in the atmosphere contribute about 1/3 of the light scattering, with sulfates and organics contributing another 1/3. The extinction coefficient for the dirtiest 20% of days is almost twice that of the cleanest days, with the exception of summer which shows little variation. The GCVTC (1996) concluded that the dirtiest days involved 60% greater light extinction resulting from human sources of pollution than on the cleanest days.

Photographs

Three photos are provided to represent the range of visibility conditions for the Grand Canyon transmissometer cumulative frequency data (Figure 9-6). The photos were chosen to provide a feel for the range of visibility conditions possible and to help relate the SVR/extinction/haziness numbers to what the observer sees.

Figure 9-6. Photographs representing visibility conditions at Grand Canyon National Park.

Figure 9-6. Photographs representing visibility conditions at Grand Canyon National Park.

Grand Canyon National Park
on a "clear" day.

Representative Conditions:
Visual Range: 290 - 380 km
b_{ext}: 13 - 10 Mm^{-1}
Haziness: 3 - 0 dv

Grand Canyon National Park
on a "average" day.

Representative Conditions:
Visual Range: 170 - 210 km
b_{ext}: 23 - 19 Mm^{-1}
Haziness: 8 - 6 dv

Grand Canyon National Park
on a "dirty" day.

Representative Conditions:
Visual Range: 60 - 75 km
b_{ext}: 65 - 52 Mm^{-1}
Haziness: 19 - 17 dv

Visibility Projections

The GCVTC (1996) projected likely visibility for Hopi Point through 2040, and the major species responsible for visibility impairment (Figures 9-7, 9-8). Reduced emissions from utilities were projected to reduce light extinction by about 1 Mm^{-1}. Light extinction caused by vehicle emissions was projected to decline until approximately 2005, and then increase through 2040. The dirtiest days have more than twice the visibility impairment than the cleanest days, and the bulk of the change results from human-related sources.

Figure 9-7. Projected “baseline” light extinction for the Grand Canyon (Hopi Point) include substantially increased contributions from vehicles (“mobile”) and from road dust (from GCVTC 1996). Left graph is for annual average; right for worst 20% of days.

Figure 9-7. Projected "baseline" light extinction for the Grand Canyon (Hopi Point) include substantially increased contributions from vehicles ("mobile") and from road dust (from GCVTC 1996). Left graph is for annual average; right for worst 20% of days.

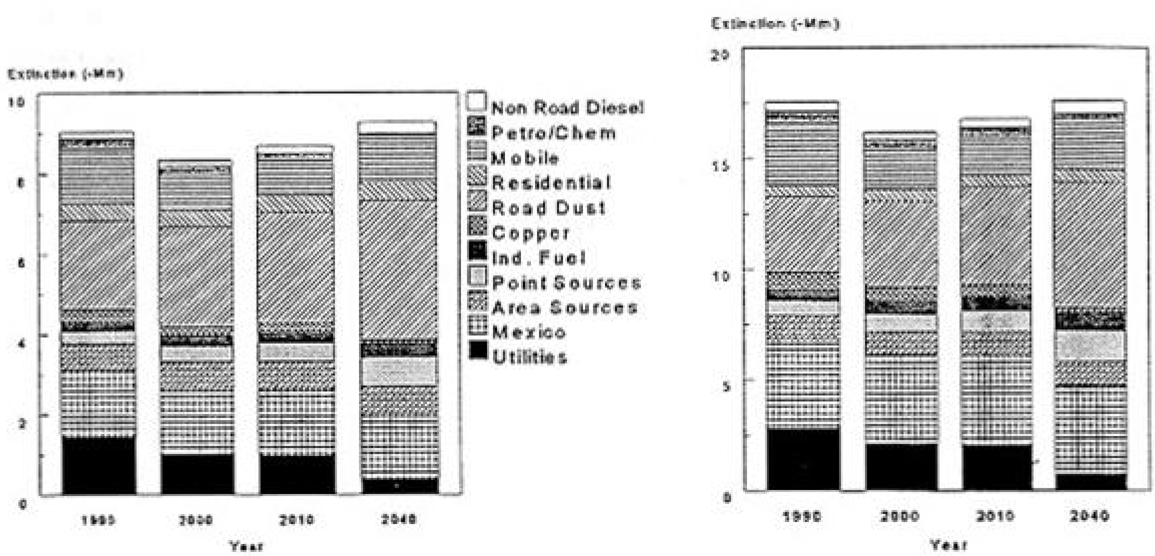
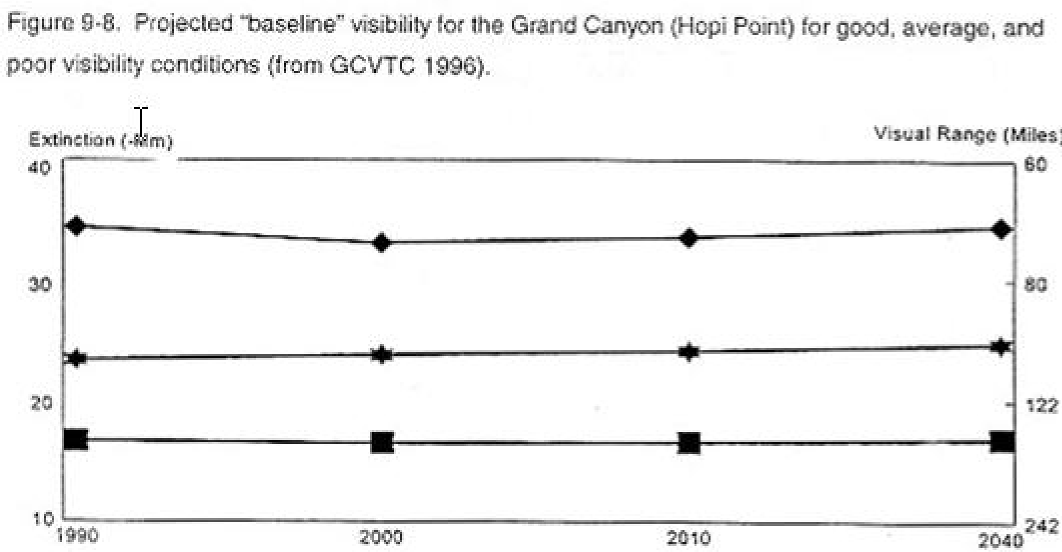


Figure 9-8. Projected "baseline" visibility for the Grand Canyon (Hopi Point) for good, average, and poor visibility conditions (from GCVTC 1996).



Atmospheric Deposition

The rates of atmospheric deposition for Grand Canyon National Park are low (Table 9-8). Precipitation pH averages about 5.3. Deposition of N averages about 1.5 kg N ha^{-1} yr^{-1}, which is similar to the rate of S deposition. No trends are apparent for N or S deposition. Estimates of dry inputs of N and S at Grand Canyon were developed as part of the National Dry Deposition Network (NDDN) for 1990 and 1991, and rates were very low (0.05 kg-N ha^{-1} yr^{-1} as nitrate, and 0.2 kg-S ha^{-1} yr^{-1} as sulfate; Clarke and Edgerton 1993). The estimate for dry deposition of nitrate-N is about 5% of the estimate of wet deposition, and dry deposition of sulfate-S is about 20% of the wet deposition rate. No evidence suggests that such low levels of deposition pose any threat to plants (see Chapter 2). The average pH (on a 5-week basis) tends to track the standard visual range measured by the transmissometers; low (acidic) pH periods tend to have low visibility (C. Bowman, personal communication).

Table 9-8. Atmospheric deposition for Grand Canyon National Park (NADP). Note the values for N and S compounds include the whole molecule and not just the N or S atoms.

	Concentrations (mg/L)			Deposition (kg ha^{-1} yr^{-1})				Conductivity (μS/mm)	Precipitation (mm/yr)
year	NH_4	NO_3	SO_4	NH_4	NO_3	SO_4	pH		
1981	0.04	0.65	1.64	0.06	0.93	2.34	5.06	1.04	143
1982	0.10	0.74	0.87	0.64	4.70	5.52	5.12	0.79	635
1983	0.09	0.68	0.70	0.47	3.52	3.63	5.25	0.61	518
1984	0.06	0.79	0.94	0.22	2.89	3.44	5.30	0.83	366
1985	0.08	0.58	0.65	0.29	2.13	2.39	5.14	0.66	367
1986	0.07	0.70	0.71	0.26	2.61	2.64	5.23	0.68	372
1987	0.05	0.42	0.40	0.12	1.04	0.99	5.47	0.45	247
1988	0.04	0.93	0.86	0.13	3.13	2.89	5.21	0.75	336
1989	0.16	1.01	0.64	0.33	2.08	1.32	5.45	0.66	206
1990	0.20	1.05	0.70	0.87	4.55	3.04	5.47	0.81	434
1991	0.09	0.67	0.52	0.28	2.08	1.62	5.28	0.58	311
1992	0.13	0.74	0.49	0.60	3.39	2.25	5.28	0.58	459
1993	0.12	0.66	0.49	0.51	2.81	2.09	5.34	0.52	426
1994	0.18	0.99	0.59	0.54	2.97	1.77	5.16	0.72	300

Sensitivity of Plants

No signs of injury from air pollution have been reported for vegetation in or near Grand Canyon National Park. A survey of ponderosa pine found no signs of injury; the plots may be relocatable (L. Mazzu, C. Bowman, personal communication.) Only a few of the Park's species have been tested under controlled conditions for sensitivity to pollutants, and none of these tests included genotypes representative of the plants in the Park. Based on the ozone concentrations required to affect very sensitive plants (such as aspen, and perhaps cottonwood), we expect that current ozone exposures could be high enough to affect some species. Current levels of ozone are probably too low to affect the conifers, and levels of SO_2 are far below any demonstrated threshold of sensitivity for any plants. In the absence of empirical evidence of any effects, no substantial problem is likely.

Water Quality and Aquatic Organisms

Seasonal water chemistry data for springs and streams draining from both the North and South Rims of the Grand Canyon National Park were presented by Foust and Hoope (1985). These authors noted that water quality monitoring in the Grand Canyon National Park has usually been associated with plans for development of springs or for planned recreational uses of surface waters. Because of the predominance of limestone, dolomite, and gypsum in the rocks of the Grand Canyon, all waters are extremely well-buffered, with the highest ANCs noted during the summer period. The range of pH for all surface waters monitored was 6.9-8.4, with alkalinities in the range of 1000 to 13000 μeq/L. Many of the geologic formations in the Grand Canyon are high in trace metals, so a number of the surface waters exceed drinking water standards and wildlife habitat acceptability standards for arsenic, selenium and chromium.

Amphibians

In the vicinity of Grand Canyon National Park, researchers have found: Great Basin spadefoot toad (*Scaphiopus intermontanus*), red-spotted frog (*Bufo punctatus*), and the canyon treefrog (*Hyla arenicolor;* Sherbrooke 1966). These species tend to breed in small pools in the sandstone, which tend to be well buffered from acidity. Another listing of amphibians found in the Grand Canyon also included: leopard frog (*Rana pipiens*), tiger salamander (*Ambystoma tigrinum)*, and Woodhouse's Toad (*Bufo woodhousii;* Tomko 1975).

Two amphibian species in Arizona are currently on the State of Arizona threatened list: Chiricahua leopard frog (*Rana chiricahuensis*) and tiger salamander (*Ambystoma tigrinum*). The northern leopard frog is a candidate for State listing. Researchers at the USGS-Biological Resources Division, Colorado Plateau Research Station are conducting surveys of leopard frogs in Arizona, including Grand Canyon to determine the status of this species. Loss of amphibian habitat in Arizona had resulted from development pressures, many of them associated with water development projects.

We conclude there is no evidence to indicate any risk to amphibians from air pollution.

Fish

The closure of the Glen Canyon Dam changed the Colorado River in the Grand Canyon from a warm, muddy river to a cold, clear one. Habitat for some fish species was eliminated, while a valuable sport fishery for exotic species was created. Native species that suffered from these habitat changes include Colorado squawfish (*Ptychocheilus lucius*), bonytail chub (*Gila elegans*), humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), roundtail chub (*Gila robusta*), and flannelmouth sucker (*Catostomus insignis*). The life histories and densities of these species in both the main stem of the Colorado River and its tributaries are not well-known. Recent manipulations of flow regimes downstream of the Glen Canyon Dam are designed to improve habitat for these endangered big river fishes. Because of the high pH and ANC in such river systems, these native and nonnative populations are unlikely to be affected by atmospheric deposition.

Recommendations for Future Monitoring and Research

General recommendations for NPS Class I areas of the Colorado Plateau are presented in Chapter 14, and many of these apply to Grand Canyon National Park. The monitoring program for air quality is the best in the region, and we have no recommendations for changes. The information from the monitoring program will continue to be fundamental to evaluating the effectiveness of the recommendations from the Grand Canyon Visibility Transport Commission (see Chapter 14). The aquatic systems that have been monitored in Grand Canyon National Park are extremely well buffered with respect to acidification. Most chemical sampling of water resources in Grand Canyon NP has been associated with well-buffered streams and springs that originate in the limestone formations in the Canyon. Little is known about seasonal streams in the North Rim region of the Park. This high-elevation region often develops a seasonal snowpack that melts quickly in the spring. Depending on the hydrology, geology, and soils found in this area, small streams and ponds could experience snowmelt dilution and nitrate pulses in spring. We recommend that areas of the Park that have significant snow accumulation be examined for evidence of resistant bedrock geology that might result in low ANC stream water. If such areas are identified, then monitoring of small headwater streams and ponds is recommended during early snowmelt.

Park Summary

Visibility is currently the only AQRV known to be impacted by pollution at the Grand Canyon, as with the other National Park Service Class I areas of the Colorado Plateau. Current levels of pollution in northern Arizona are high enough to produce haze and obscure the important vistas of the Park and surrounding areas. Any increase in aerosols will undoubtedly impair visibility further; substantial reductions in aerosols would be needed to restore pristine conditions at the Grand Canyon. Visitation to the Grand Canyon National Park is expected to continue to increase in the future, reaching 6 million visitors by 2005 (Rowlands 1993).

Little information has been collected on air pollution effects on the Park's biota. No sign of air pollution impacts on plant or animal species has been reported; ozone concentrations are high enough that some impact is possible for sensitive plants, but SO_2 concentrations are too low to affect plants.

References

Arizona Radiation Regulation Agency. 1994. CY 1994 Annual report. Radiation Measurements Laboratory.

Bradley, R., Karlstrom, K.E., Hawkins, D.P. and Williams, M.L. 1996. Tectonic evolution of paleoproterozoic rocks in the Grand Canyon: insights into middle-crustal processes. Geological Society of America Bulletin 108:1149-1166.

Chronic, H. 1988. Pages of Stone, Geology of Western National Parks & Monuments, 4: Grand Canyon and the Plateau Country. The Mountaineers, Seattle, Washington, 158 pp.

Clarke, J.F., and E.S. Edgerton. 1993. Dry deposition flux calculations for the National Dry Deposition Network. Contract #68-02-4451 Report to USEPA, Research Triangle Park.

Copeland, S., Savig, K., Adlhoch, J., and Sisler, J. 1995. Integrated Report of Optical, Aerosol, and Scene Monitoring Data, Grand Canyon National Park - March 1993 through February 1994.

Elston, D.P. 1989. Middle and Late Proterozoic Grand Canyon Supergroup, Arizona. Pp. 94-105 in: Geology of Grand Canyon, Northern Arizona. American Geophysical Union, Washington, D.C.

Foust Jr., R.D. and Hoppe, S. 1985. Seasonal trends in the chemical composition of Grand Canyon waters. National Park Service. 47 pp.

Grand Canyon Visibility Transport Commission (GCVTC) 1996. Recommendations for improving western vistas. Report of the GCVTC to the EPA, June 1996, Western Governors Association, Denver.

National Atmospheric Deposition Program (NADP). 1981-current. Data Summary. Natural Resources Ecology Lab, Colorado State University, Fort Collins, Colorado.

NPFlora Alphabetical Listing, May 1995.

NPLichen Alphabetical Listing, May 1995.

Radian Corporation. 1994a. Development of an emissions inventory for assessing visual air quality in the western United States. Final report to the Grand Canyon Visibility Transport Commission and Project VARED. Radian Corporation, Sacramento, California.

Radian Corporation. 1994b. Summary of significant findings. Development of a micro inventory of air pollutant emissions for Grand Canyon National Park, Arizona. Radian Corporation, Sacramento, California.

Rowlands, P.G. 1993. Forecasting visitation at Grand Canyon National Park using time series analysis. Technical Report NPS/NAUGRCA/NRTR-93/03, National Park Service, Flagstaff.

Sherbrooke, W.C. 1966. Ecologic distribution of the amphibians and reptiles of the Mt. Trumbull-Toroweap Valley region of northern Arizona. M.S. Thesis, University of Arizona, Tucson.

Threatened and Endangered Species Information Institute. 1993. U.S. Threatened and Endangered Species, Volume 2, Plants.

Tomko, D.S. 1975. The reptiles and amphibians of the Grand Canyon. Plateau 47(4): 161-166.

Van Ee, J.J. 1979. Unpublished study. Personnel exposure to automotive pollutants at the south entrance, Grand Canyon National Park. EPA Office of Research and Development, Las Vegas, Nevada.